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Asymmetric group velocity dispersion and pulse distortion in a uniform fiber Bragg grating

Sanjeev Kumar Raghuwanshi* and Srinivas Talabattula
Applied Photonics Laboratory, Department of Electrical Communication Engineering, Indian Institute of Science, Bangalore-560 012, India

E-mail sanjeevkr@ece.iisc.ernet.in

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Abstract : In a uniform fiber Bragg grating, if the input signal is a Gaussian pulse the dispersion is zero near center wavelength and becomes appreciable only near the band edges and side lobes of the reflection spectrum However for chirped Gaussian pulses, group velocity dispersion and the reflected light must become asymmetric Here the chirped Gaussian pulses can be treated as a symmetric but nonuniform input signal The present paper describes that for the case of symmetric Gaussian pulse, the group velocity dispersion and pulse distortion remain symmetric however strong the grating may be On the other hand both tend to be more asymmetric for the case of strong grating while the input signal is symmetric with nonuniform shape

Keywords : Coupled mode theory of fiber Bragg gratings, group velocity dispersion effect, chirped Gaussian pulses

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1. Introduction

Recently, there has been growing interest in the dispersive properties of fiber Bragg gratings for applications such as dispersion compensation, pulse shaping and fiber and semiconductor laser components [1]. Although many of these rely on the ability to tailor the dispersion in the nonuniform gratings, here we introduce the basis for determining delay and dispersion from the known (complex) reflectivity of a uniform Bragg grating. The amplitude and power reflection coefficients in a uniform fiber Bragg grating for the case of non-phase-matched contradirectional modes coupling are given by [2–14] :

$$\rho|_{z=0} = \frac{-\kappa \sinh(\Omega L)}{\frac{\Gamma_1}{2}\sinh(\Omega L) + j\Omega\cosh(\Omega L)}, \tag{1}$$

*Corresponding Author

$$|\rho|^2 = \frac{\left[\Omega^2 + \left(\frac{\Gamma_1}{2}\right)^2 \sinh^2(\Omega L)\right]}{\Omega^2 \cosh^2(\Omega L) + \left(\frac{\Gamma_1}{2}\right)^2 \sinh^2(\Omega L)}. \tag{2}$$

Here the parameters Γ_1, k and Ω represent the mismatch between the momentum of the mode with the refractive index perturbation, mode coupling coefficient and the phase detuning parameter, respectively. Turan Erdogan [2] presents a derivation of the above equations. The group delay and dispersion of the reflected light can be determined from the phase of the amplitude reflection coefficient [2]. If we denote $\theta_\rho \equiv phase(\rho)$ then, the delay time τ_ρ for light reflected off a grating is

$$\tau_\rho = \frac{\theta_\rho}{d\omega} = -\frac{\lambda^2}{2\pi c}\frac{d\theta_\rho}{d\lambda}. \tag{3}$$

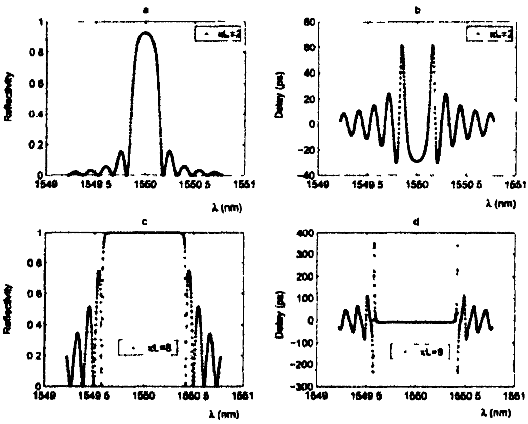

Figure 1. Calculated reflection spectra and corresponding group delay for an uniform Bragg grating with (a), (b) $\kappa L = 2$ and (c), (d) $\kappa L = 8$.

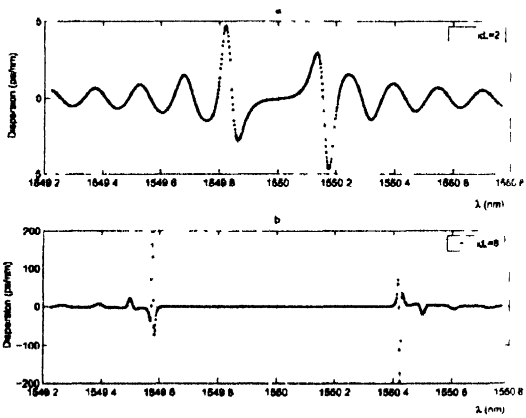

Figure 2. Calculated group velocity dispersion for the same case as Figure 1 with (a) $\kappa L = 2$ and (b) $\kappa L = 8$.

Figure 1 shows the delay τ_ρ calculated for the two examples of the grating. We see that for unchirped uniform grating both the reflectivity and delay are symmetric about the center wavelength. Since the dispersion d_ρ (in ps/km) is the rate of change of delay with wavelength, we find

$$d_\rho = \frac{d\tau_\rho}{d\lambda}$$

$$= \frac{2\tau_\rho}{\lambda} - \frac{\lambda^2}{2\pi c}\frac{d^2\theta}{d\lambda^2}$$

$$= -2\pi c\lambda^2 \frac{d^2\theta_\rho}{d\omega^2} \tag{4}$$

In a uniform grating, the dispersion is zero near center wavelength as shown in Figure 2 and becomes appreciable only near the band edges and side lobes of the reflection spectrum, where it tends to vary rapidly with wavelength.

2. Asymmetric pulse distortion

Gaussian pulses can be considered as a symmetric signal, on the other hand chirped Gaussian pulses can be presumed to be nonuniform but symmetric signal. Figure 3 demonstrates various kinds of Gaussian pulses with different values of chirp parameter [3]. Now if we feed these Gaussian pulses to a uniform Bragg grating, we can visualize the pulse distortion as well as reflected mode field due to these chirp factors. We consider only the positive chirped Gaussian pulses into analysis because the negative chirp factor will only reverse the whole effect. First we present the results of chirp free pulses. Figure 4 shows the fundamental reflected mode field and corresponding peak power reflection spectrum.

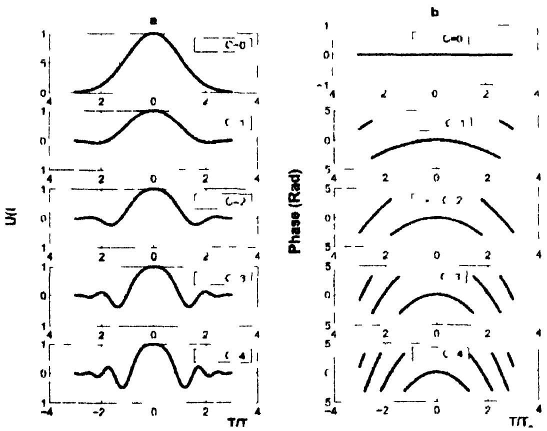

Figure 3. Gaussian pulses (left side) and corresponding phase spectrum (right side) for various values of chirp factor.

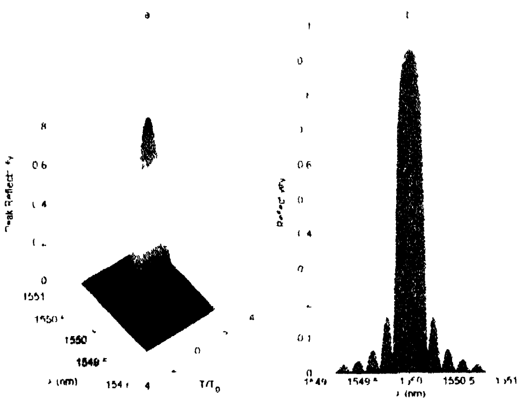

Figure 4. Fundamental reflected mode field and corresponding peak power reflection spectrum while $C = 0$ and $\kappa L = 2$

Figures 5 and 6, show the reflected light for the two cases, one for weak grating ($\kappa L = 2$) and another for strong grating ($\kappa L = 6$), while chirping factor is kept at $C = 0$ and $C = 2$, respectively. One can see from Figures 5 and 6 that for chirp free pulses the reflected power is symmetric in both the cases, while for $C = 2$, they are considerably asymmetric. Reflected pulse would be more asymmetric for strong grating.

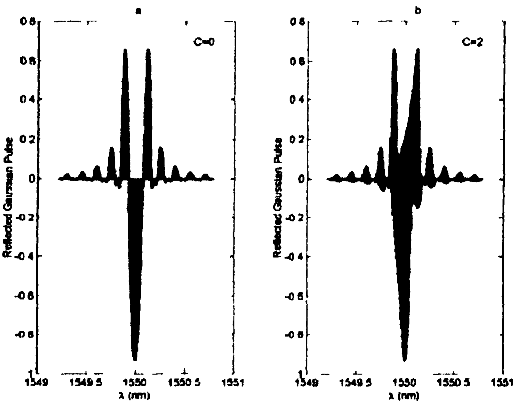

Figure 5. Reflected light at $z = 0$, while (a) $C = 0$, (b) $C = 0$ and $\kappa L = 2$

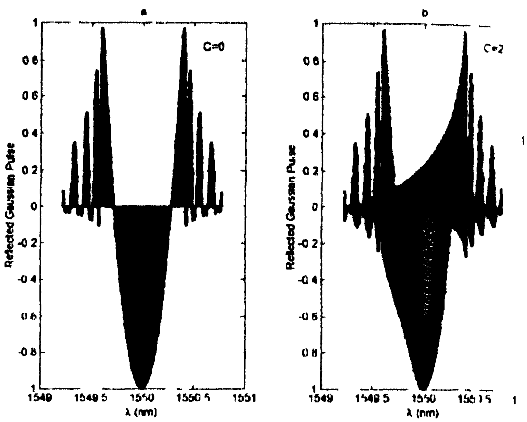

Figure 6. Reflected light at $z = 0$, while (a) $C = 0$ (b) $C = 2$ and $\kappa L = 8$

3. Asymmetric group velocity dispersion

Dispersion plots and corresponding contour maps for various values of chirp factors are shown in Figures 7, 8 and 9, respectively for $\kappa L = 2$. For the case of chirp free pulse

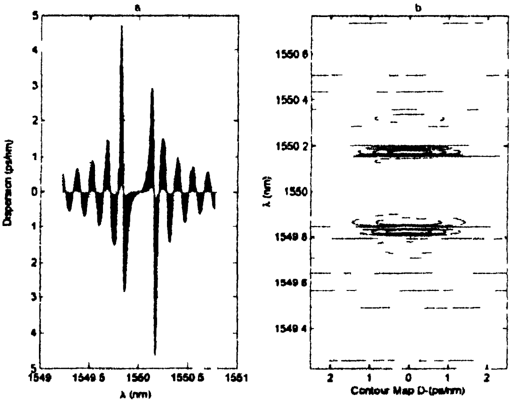

Figure 7. Dispersion and corresponding contour map for $C = 0$ and ($\kappa L = 2$)

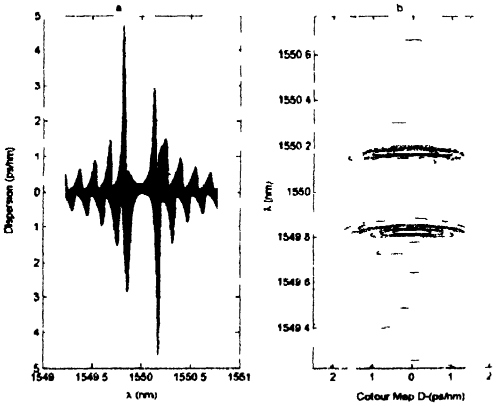

Figure 8. Dispersion and corresponding contour map for $C = 2$ ($\kappa L = 2$)

the dispersion is zero at center wavelength where the peak reflection occurs; on the other hand, for considerably chirped pulses the dispersion curve no longer remains symmetric but picks up a considerable curvature. For highly chirped Gaussian pulses ($C = 4$), the dispersion curve picks up larger curvature at all the wavelength of interest This feature can be considered as an asymmetric response of uniform fiber Bragg grating even for weak grating case. Figures 10 and 14 show the fundamental reflected mode field and corresponding peak power reflection spectrum for the case of moderately strong ($\kappa L = 4$) and strong grating ($\kappa L = 6$). The reflection bandwidth of the spectrums are 0.4 nm (Figure 10) and 0.6 nm (Figure 14), respectively. Dispersion and contonr maps for different values of C and κL are displayed in Figures 11–13. Comparison of

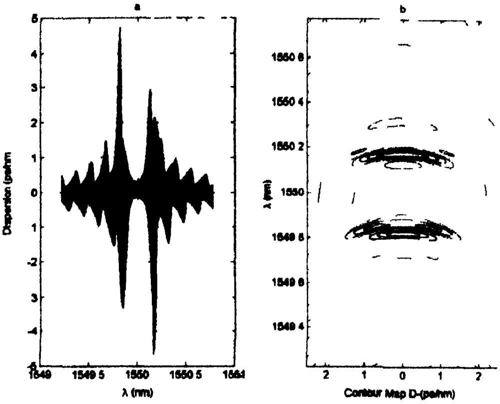

Figure 9. Dispersion and corresponding contour map for $C = 4$ ($\kappa L = 2$)

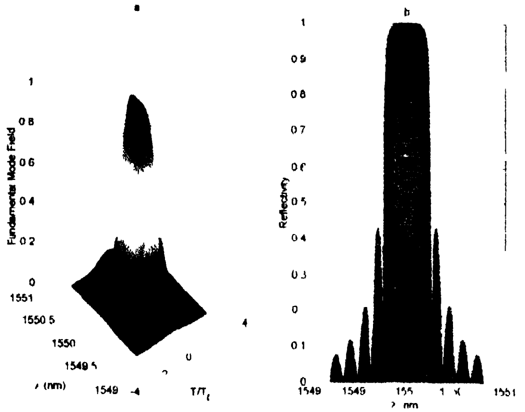

Figure 10. Fundamental reflected mode field and corresponding peak power reflection spectrum while $C = 0$ and $\kappa L = 4$

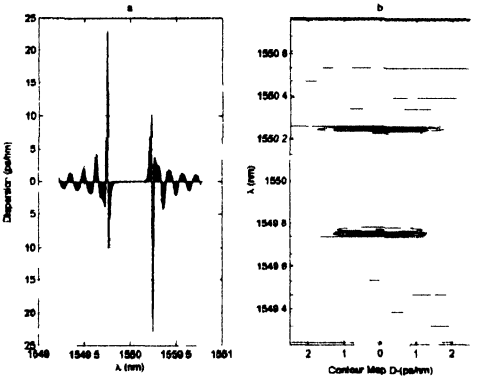

Figure 11. Dispersion and corresponding contour map for $C = 0$ ($\kappa L = 4$)

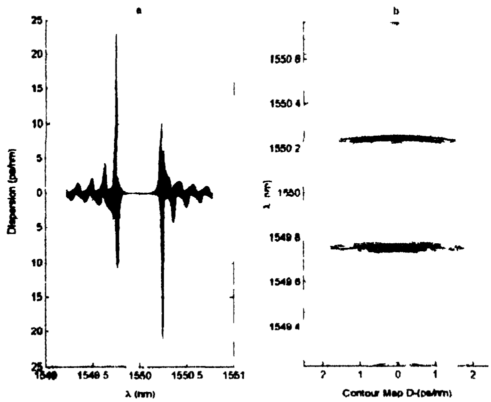

Figure 12. Dispersion and corresponding contour map for $C = 2$ ($\kappa L = 4$)

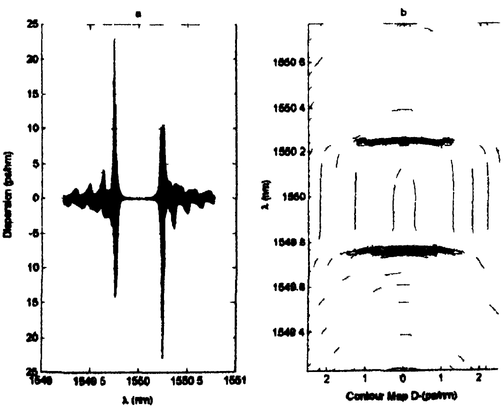

Figure 13. Dispersion and corresponding contour map for $C = 4$ ($\kappa L = 4$)

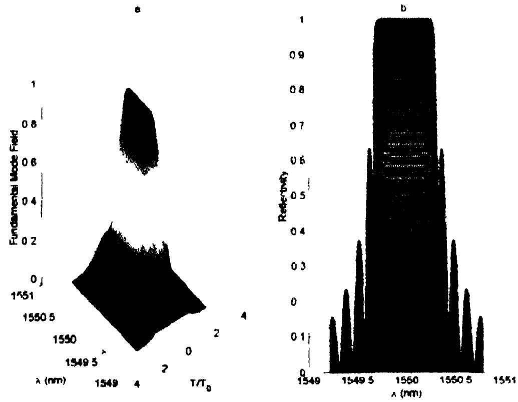

Figure 14. Fundamental reflected mode field and corresponding peak power reflection spectrum while $C = 0$ and $\kappa L = 6$

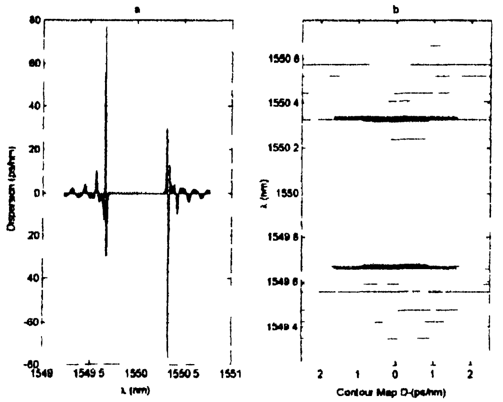

Figure 15. Dispersion and corresponding contour map for $C = 0$ ($\kappa L = 6$)

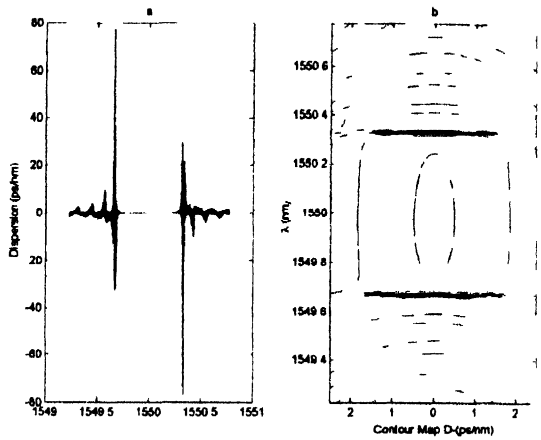

Figure 16. Dispersion and corresponding contour map for $C = 2$ ($\kappa L = 6$)

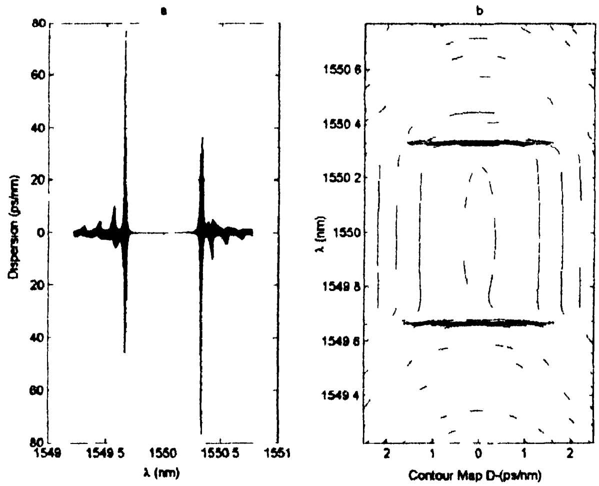

Figure 17. Dispersion and corresponding contour map for $C = 4$ ($\kappa L = 6$)

Figures 7, 11 and 15 suggests that for the case of symmetric Gaussian pulse the zero dispersion bandwidth is more pronounced for the case of strong grating (B.W. $\approx$ 0.6 nm) [15] while for chirp free pulses dispersion accumulates more for some singular points in the case of a strong grating (±80 ps/nm). The dispersion graph becomes significantly asymmetric for strong grating for considerably chirped Gaussian pulses. It is quite symmetric for weak grating (±5 ps/nm) case even for the same simulation parameters.

4. Conclusion

We have found that for the case of strong grating the dispersion is large at some particular point of bands which may be due to rapid phase variations. Infact, the weak grating shows lesser dispersion but the dispersion is more spread out over the band as compared to strong grating The dispersion graph tends to be more asymmetric for the strongly chirped pulses. Simulation also shows that the dispersion is high due to strong grating at some singular point of wavelength There is no effect of chirp factor on absolute value of dispersion as such The only advantage of using strong grating for chirp free pulse is that we can achieve a large band of zero dispersion at some center wavelength where the peak reflection occurs

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